SOME EXPERIMENTS WITH THE SMALL TRANSMITTING LOOP AERIAL

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Introduction

IN SEVERAL OF MY PREVIOUS articles, I have discussed various forms of loop aerials for receiving radio signals. Such aerials are unsuitable for transmitting signals and I thought I would now turn my attention to small loops suitable for transmitting. By definition, the small transmitting loop is one which has a circumference less than one quarter of a wavelength.

Because of its small size, it is possibly an attractive proposition for someone with inadequate space to erect a larger aerial. For example, an efficient loop can be constructed for the 14MHz band about one metre square. The small loop might also be attractive for operation in the field.

The small transmitting loop has been around for a long time but it appears to have been improved for amateur radio by Ted Hart W5QJR who developed a set of equations to calculate the various loop constants and set down parameters for a new design (refer *QST*, June 1986). The latest issue of the ARRL Antenna Handbook also has some excellent material on both transmitting and receiving loop aerials.

The section on small transmitting loops was written by Ted Hart, and this includes his design formulae plus a complete set of worked-out data for practical loops. The design formulae, taken from this section, are repeated in the appendix at the end of our article.

To gain some experience with the small transmitting loop, I experimented with several forms of the loop essentially for use at 14MHz. I selected this band because the loop dimensions, suitable for 14MHz, enabled construction to be easily handled.

Because of its narrow bandwidth, the transmitting loop tuning has to be tracked as frequency is shifted across the band. Ted Hart suggests remote motor controlled tuning. In the course of my discussion, I will introduce another idea which I found satisfactory to track the tuning across the band without the use of the motor controlled tuning.

Halos can be handy, but for flat dwellers loops can be heaven sent.

From Ham Radio Today — *April 1988*

The Difference Between Transmitting & Receiving Loops

One might well ask why our receiving loops are unsuitable for transmitting. Most other aerial systems are reciprocal in operation, so why not these? To answer this, we must point out that in our receiving loop we are interested only in signal voltage. The loop is parallel tuned and coupled to the high impedance input of an amplifier enabling the Q factor of the tuned loop to multiply the signal voltage. In our receiving loop, we are not really interested in power efficiency. If we were, we would find that most of the signal power is consumed in the loss resistance of the loop. However, to transmit a signal, RF power must be transferred into the loop and developed across the radiation resistance of the loop.

The radiation resistance of a small loop is typically only a fraction of an ohm. To achieve any reasonable figure of efficiency, the loop loss resistance must also be a very low value otherwise most of the power is dissipated in the loss resistance. Wire loops as used in receiving have a loss resistance in the order of ohms, and to achieve the low loss resistance needed, transmitting loops are made with large diameter copper tube. Special attention must also be given to minimising resistance in the loop tuning and matching components, particularly the loop tuning capacitor.

The equivalent circuit of the loop aerial is shown in figure 1. The predominant component is the loop inductive reactance, which is large compared with the sum of the radiation resistance Rr and the loss resistance RL. Because of the high ratio between reactance and resistance, Q factors are extremely high, in the order of many hundreds, and often greater than 1000. The loop is set to resonance at the operating frequency by parallel capacitance Ct connected across the loop. Maximum operating frequency is limited to a frequency set by the resonance of the loop inductance L with the loop stray capacitance Cd. Because of the high Q, bandwidth of the loop is very small and it is necessary to alter the tuning capacitance when changing frequency more than a few kHz. The Ted Hart design calls for remote control of the tuning network which adds some complication to the construction of the loop aerial system.

Tuning Capacitors

Selecting the tuning capacitor requires special attention. In the QST article, Hart used the two halves of a split stator capacitor in series so there were no wiper contacts, normally in contact with the rotor, to add series resistance. He also recommended the capacitor plates be welded together to reduce resistance rather than be separated by spacers.

Because of the high Q factor, the voltage developed across the capacitor is quite high. Even using only 100 watts of power, the voltage can be as high as 10 to 15 kilovolts. Not only must the capacitor be selected for low resistance, but also its plates must be wide spaced to withstand the voltage. Calculation of the voltage developed is included in the appendix. As a guide to the spacing required, breakdown voltage in air is around 30 peak kilovolts per centimetre.

Matching

One way to match a 50-ohm line to the

low resistance of the loop is to use a balanced L network of shunt Xc and series XL. As a total reactance equal to the inductive reactance of the loop less the series reactance required for matching. The matching circuit is shown in figure 2. In my initial tests, I used this system, but it does have its problems. First of all, two isolated tuning capacitors must be ganged together. A split stator capacitor with common rotor cannot be used. I did find I could operate the tuning quite well without ganging by matching the setting of the two series capacitors at the centre of the band and adjusting only one to tune over the band. I also found the input shunt capacitor could be fixed for the whole band.

Apart from the physical problems of ganged capacitors, the system has inherent loss in the two series capacitors as they provide loop tuning connected via their stator wipers. One way to reduce the effect of this loss resistance is to add capacitance across the loop, in effect increasing the value of Cd. By doing this, the parallel circuit loop constants (figure 3a) can be considered as equivalent to a simple series circuit of inductance and resistance (figure 3b). The equivalent resistance component is much higher than the series resistance of the loop (Rr + RL). The higher the value of Cd, the higher is this component and hence the less effect of loss resistance in the tuning capacitors. Of course, too much capacitance Cd will prevent the loop from being brought to resonance. The fixed capacitor added must also be low loss and withstand the high voltage. I made use of a short length of heavy duty coaxial cable which provides a capacitance of around one picofarad per centimetre. This worked quite well for some time until one day the high voltage developed by the loop blew a hole through the polythene dielectric. A better idea would have been to use fixed plates spaced in air sufficient to withstand the voltage.

All in all, the balanced L network has its limitations as a matching system for the transmitting loop and, in fact, Ted Hart described it as an inefficient system. In his system (figure 4) matching is carried out via a gamma match at the bottom of the loop and separated from the tuning capacitor which is connected across the open ends of the loop at its top. The tuning capacitor is coupled to a stepper motor with gear drive to give adequate tuning resolution. The motor is remotely controlled via a cable which runs through the inside of the loop tubing.

The system I finally installed separated the matching system from the loop tuning, as Ted Hart had done, but made

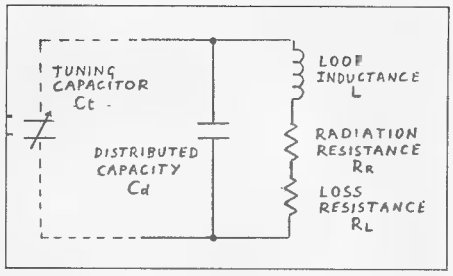

Figure 1. Equivalent circuit of the loop aerial

use of a delta match in place of the gamma match. The reason for this will be explained further on.

The Loop

Ted Hart has pointed out that, for a given length of conductor, a circular loop (or something approaching a circle such as a hexagon) gives more loop area than any other shape and hence it is the best choice of shape. I accept this, but my receiving loops have all been square because it was easy to make up square or diamond shaped loops using a simple frame of two crossed pieces of wood. My first transmitting loops were made up the same way using the outer conductor of heavy duty coaxial cable and, to make a direct comparison, the copper tube loop was followed up with a square of the same size.

My final loop was made up 0.97 metre

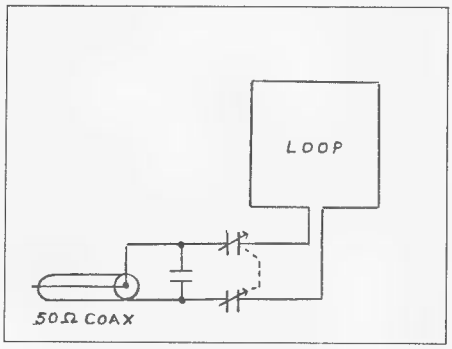

Figure 2. Matching the loop aerial with the balanced L network

square with 3/4 inch copper tube obtained from the local plumber. The tube was cut and assembled to the form shown in figure 5 using copper elbows for the right-angle joints. All joints were silver soldered, thanks to John VK5JL. Details of the loop and calculated constants for 14.2MHz are as follows (Imperial measurements are used because the published formulae, as repeated in the appendix, are given in these units):

Tube Diameter d = 0.75 inch
Circumference S = 12.7 feet
Area A = 10 square feet
Frequency f = 14.2MHz
Power P = 100 watts
Radiation Resistance Rr = 0.137 ohm
Loss Resistance RL = 0.064 ohm
Efficiency n = 68%
Inductance L = 3.27 micro-henry
Q factor = 723
Inductive reactance XL = 291 ohms
Bandwidth B = 19.6kHz
Distributed capacity Cd = 10.4pF
Capacitor potential Vc = 4587V
Tuning capacitor Ct = 28pF

Whilst the loop design was aimed at the 14MHz band, the loop can be tuned to other bands, and calculated constants for some of these are as follows:

Frequency	Rr	RL	Efficiency	Tuning C
7MHz	0.008	0.045	15%	148pF
10MHz	0.034	0.053	39%	67pf
21MHz	0.66	0.077	89%	8pf

(Rr and RL are in ohms)

It can be seen that operation at as low a frequency as 7MHz is possible, but with low efficiency. The efficiency is improved as the frequency is increased, and at 21MHz efficiency is very high. Operation at 28MHz is not possible because self-resonance occurs at a frequency just below 28MHz. The calculations do not take into account losses in the tuning capacitor which could further decrease the efficiency.

The advantage of the large diameter copper tube is demonstrated by comparing with the same sized loop utilising the outer copper braid of the coaxial cable. (The braid is 5/16 inch diameter). The calculated loss resistance of the coax loop at 14.2MHz is 0.14 ohm and the calculated efficiency is 41 per cent. This compares with 68 per cent for the 3/4 inch copper tube loop.

Tuning the Band Without the Drive Motor

I found a way to remotely tune over the band without the drive motor. The gamma match is replaced by a delta match which is fed with 300 ohm balanced TV open wire line. This type of line has extremely low loss at HF even if used in a tuned mode. The loop tuning capacitor is set for resonance in the centre of the band (say 14.2MHz) and at this frequency the delta taps are adjusted for a 300 ohm match. The open wire line is fed from the transmitter via some form of balanced tuning system (refer figure 6). The Z match tuner does the job very nicely.

To set up the system, the tuner is first loaded into a 300 ohm resistor and adjusted for matching at the centre frequency. This can be done by connecting a noise bridge at the transceiver output and operating in the receive mode. The open wire line is then connected in place

of the resistor and the loop tuning is adjusted for best balance of the noise bridge. Some adjustment of the delta match taps might also be required, but the tuner adjustment must not be altered from the setting determined using the 300 ohm resistor. Remove the noise bridge and verify that there is low SWR on transmit. If necessary, the loop tuning can be trimmed for best SWR. This whole operation is a little tricky because the loop tuning must be carried out within hearing distance of the noise bridge in the receiver. If the loop tuning is carried out using the SWR meter, the SWR meter must be within vision. I found it necessary to tune the loop with it first located close to the transceiver and connected via a short length of the open wire line. If matched properly, the loop tuning can be assumed to be correct for whatever length of line is ultimately used.

Another problem is that the loop is very susceptible to detuning if in close proximity to any conductors, including the human body. This makes setting the tuning capacitor by hand a little tricky.

Now, having set the loop tuning and matching, this is how the system works. If we shift very far from the centre frequency, the high Q loop goes out of tune. The procedure is then to readjust the tuner for low SWR, in effect reflecting down the open wire line into the loop a reactance sufficient to correct for the detuning. Off the centre frequency, the open wire line works partly in a tuned mode. The nature of the impedance change placed across the line by the tuner is obviously a function of line length, but for the various random lengths of line I use myself, the Z match tuner was easily able to handle the correction over each amateur band tested.

For the copper tube loop described, I found a good match to the 300 ohm line was obtained if the delta match taps were set as follows:

14 and 21MHz — each tap 17.5cm from centre

10MHz — each tap right to the end of the tube elbows, 44cm from centre

7MHz — fit the taps on the side tubes, 8.5cm from the top

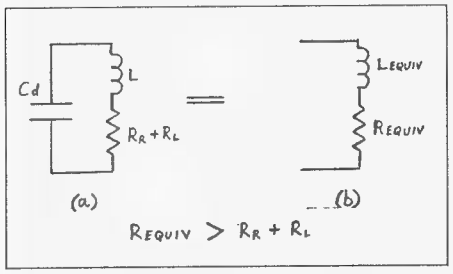

Figure 3. Added shunt capacitance makes the loop resistance (Rr+RL) appear as a higher equivalent value

You may have noticed by now that my delta match is at the top of the loop and tuning across the open ends is at the bottom.

This is the opposite of the Ted Hart loop. One reason for this is that with the heavy variable capacitor at the bottom, the centre of gravity is lower and it hangs better on my rope support. A second reason is that tests were carried with the loop just above body level, and by running the feeders to the top of the loop, they were kept clear above head height.

I experimented with a further idea of leaving the taps set at the 14/21MHz position and correcting for the mismatch at 7 and 10MHz with the tuner. This would allow the loop to work at high efficiency in the higher DX bands whilst also permitting lower efficiency operation for more local contacts on the 7MHz band. (Quite apart from any loss due to mismatch, it was pointed out earlier that, in any case, the efficiency on 7MHz is inherently low due to the low ratio of Rr to RL). Unfortunately, fixing the matching tap settings for all bands does not solve all the problems for multiband operation. The loop tuning capacitor still has to be set to a different fixed value for each band. So my idea of a partly tuned line to eliminate remote motor control of the tuning capacitor is essentially a one-band system, unless the capacitance is pre-switched, or remotely switched when changing bands.

I should make some comment about the 300 ohm open wire TV line discussed. Unfortunately, it is difficult to obtain these days unless a disposal source can be found. Over past years it was in common use to feed TV antennas in fringe TV areas. If this type of line is unavailable, open wire line can be made up using parallel wires kept apart by pieces of perspex, polystyrene or similar insulating material. Although more lossy for the tuned feeder mode of operation, a last resort could be 300 ohm TV ribbon.

Operational Performance

One confusing thing in the literature published on the transmitting loop is the loop directivity. The material submitted by Ted Hart shows a bi-directional radiation pattern with maximum signal in line with the plane of the loop and minimum signals or null at right angles to the plane. This is the same as normally expected around a small receiving loop. I was initially a little confused when my one-metre-square loop operating on 14MHz clearly provided a bi-directional pattern with its maximum signal at right angles to the plane of the loop. An answer to this anomaly seems to be in the following: The receiving loop pattern is based on the fact that the current is uniform around the perimeter of the loop. When the perimeter is around 0.1 wavelength or greater, this ceases to be true, and the pattern changes, taking up a pattern more like the large loops such as the quad.

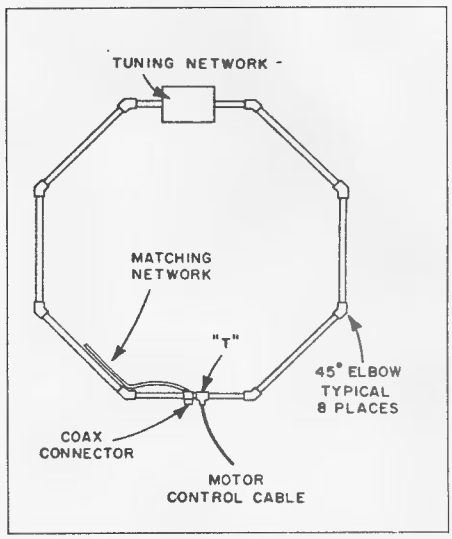

Figure 4. The small transmitting loop — design by Ted Hart W5QJF

The perimeter of my loop is around 0.2 wavelength at 14MHz and around 0.1 wavelength at 7MHz. The loop pattern appeared similar for both 14 and 7MHz. A rough test was carried out on the loop in a receive mode using an oscillator source. This was moved around the loop in a circle of 6m radius at loop height above the ground. Definite nulls were recorded in line with the plane of the loop. At six metres we are in the induction field of the loop and I don't know whether this makes the measurement an anomaly. Nevertheless, several reports from other stations worked on 14MHz supported maximum signal when the loop was rotated at right angles to the plane of the loop.

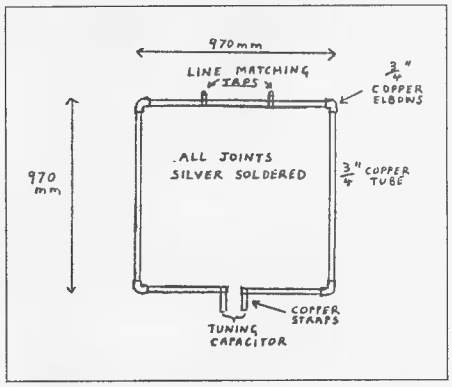

Figure 5. Detail of the loop assembled by VK5BR

Whilst the field pattern horizontally in line with the loop might have pronounced nulls, at higher radiation angles the pattern becomes more omni-directional. I found I could work distant stations in all directions without rotating the loop. For sky wave operation there might be only a slight advantage in having a facility to rotate the loop. Another factor not addressed is the effect of the ground reflected signal. We know that with a dipole we can control the angle of maximum radiation by the height of the dipole above the ground. I obtained quite encouraging results with the loop fairly close to the ground. Perhaps these results could have been improved had the loop been mounted higher.

Operational tests with other stations were first carried out on 14MHz. The loop was set up in my willow tree with the bottom of the loop about one metre above the ground. Switching was arranged so the transceiver could be changed, during transmission, between the loop and either of two full-sized wire aerials oriented in different directions. Signal reports were received from interstate and overseas stations and I was repeatedly told there was little to choose between the signal strength from the loop and that from the particular wire aerial used. This seemed very encouraging considering the small size of the loop. At one stage, I had the loop set up for adjustment inside my garage, which is a steel structure except for one small wooden door and two small windows. I was surprised to find that, even in this shielded environment, I was able to carry out a QSO with stations in NSW and Tasmania. I was also sending quite a strong signal into Victor Harbour over the other side of the ranges.

Some further QSOs were carried out with interstate stations when the loop was tuned up on 7MHz. This, of course, was back under the willow tree. As might be expected because of the lower efficiency on this band, signal strength reports for the loop were two or three S points below that given for my half-wave inverted V.

Summary

An introduction has been given to the small transmitting loop aerial. Considering its small size, its performance is quite surprising. If one has space for a full sized aerial then there is not much point in building this type of loop. However, if you have limited space, or you need a compact aerial system to operate in the field, then the small transmitting loop might be a proposition. Its biggest problem is its narrow bandwidth and the need to carefully peak up its tuning whenever shifting frequency across the band. This can be done using a remote controlled motor with reduction gearing system driving the tuning capacitor. I have suggested another method using a partly tuned open wire TV transmission line.

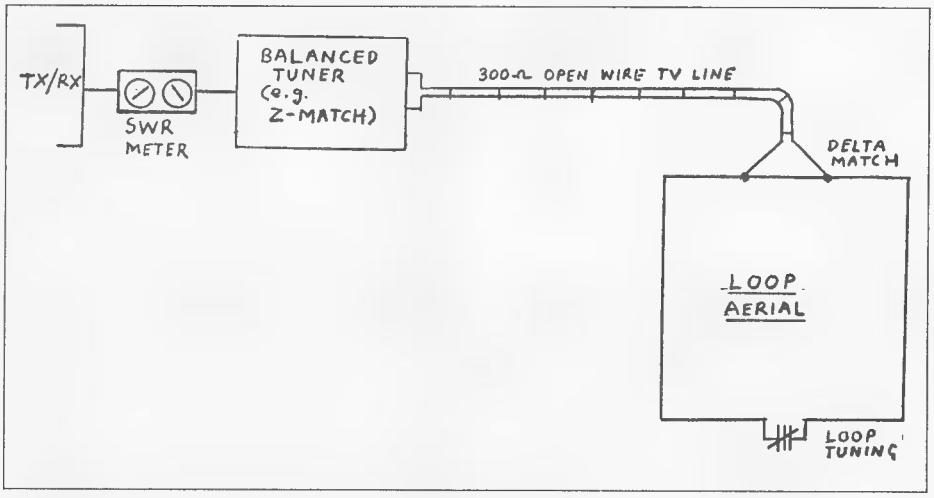

Figure 6. Matching system using open wire TV line. The loop is resonated with the line matched at band centre frequency. To tune the loop across the band, reactance is reflected down the line.

Copper tube and copper elbows for construction of the loop can be obtained from local plumbing suppliers. A suitable tuning capacitor, with low resistance loss and plate spacing to withstand the high voltage, might be more difficult to procure.

If you are interested in the small transmitting loop, I suggest you read at least one of the two references given below.

References

1. Hart, Ted W5QJR — Small, High-efficiency Loop Antennas — *QST* June 1986.

2. Loop Antennas — Chapter 5 — *The ARRL Antenna Handbook,* 1988 issue.

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APPENDIX

LOOP DESIGN FORMULAE FROM THE ARRL ANTENNA HANDBOOK

Basic Equations for a Small Loop

Radiation resistance, ohms	$R_R = 3.38 \times 10^{-8} (f^2A)^2$
Loss resistance, ohms	$R_L = 9.96 \times 10^{-4} \sqrt{f} \frac{S}{d}$
Efficiency	$\eta = \frac{R_R}{R_R + R_L}$
Inductance, henrys	$L = 1.9 \times 10^{-8} S\left(7.353 \log_{10} \frac{96\,S}{\pi\, d} - 6.386\right)$
Inductive reactance, ohms	$X_L = 2\pi fL \times 10^6$
Tuning capacitor, farads	$C_T = \frac{1}{2\pi f X_L \times 10^6}$
Quality factor	$Q = \frac{f \times 10^6}{\Delta f} = \frac{X_L}{2(R_R + R_L)}$
Bandwidth, hertz	$\Delta f = \frac{f \times 10^6}{Q} = (f_1 - f_2) \times 10^6$
Distributed capacity, pF	$C_D = 0.82S$
Capacitor potential, volts	$V_C = \sqrt{PX_LQ}$

where
- f = operating frequency, MHz
- A = area of loop, square feet
- S = conductor length, feet
- d = conductor diameter, inches
- η = decimal value; dB = $10 \log_{10} \eta$
- P = transmitter power, watts

More on the Small Transmitting Loop Aerial

Addendum to the Article in November 1991 issue of *Amateur Radio*.

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Anomaly in Formulae

A list of design formulae for the transmitting loop aerial was included in the article. Please note that the formula quoted for the tuning capacitor Ct actually refers to the total capacitance needed to tune the loop and hence the distributed capacitance Cd must be subtracted to determine the capacitance added.

Radiation Pattern

In the text of the article, I stated that I was a little confused at finding the directivity of the loop to be different from that expected. My initial tests were carried out by moving an oscillator source around the loop and observing the output level change in a receiver connected to the loop. The signal was radiated directly from the oscillator tuning coil and I have since realised that this gave an anomalous result. Normal response from a small loop is maximum signal in line with the plane of the loop and minimum signal at right angles to that plane. I have more recently assembled a field strength measuring instrument using the rod as an aerial. I am pleased to report that using the rod in the vertical plane, the measurements conform to this pattern and there is no longer any confusion.

It is interesting that at a radiation angle of 0 degrees, the radiation pattern is bi-directional with vertical polarisation. Two sharp nulls occur at right angles to the plane of the loop but these gradually disappear as the radiation angle is increased. At 90 degrees, the radiation pattern is almost non-directional with horizontal polarisation. At intermediate angles, there is a mixture of both vertical and horizontal polarisation.

Response Close To Ground

Trevor Smith VK2ECU sent me a copy of an article on the early Army Transmitting Loop written by Kenneth H Patterson in *Electronics*, August 1967. This draws attention to a very important feature of the loop. A horizontally polarised wave reverses phase when it is reflected from the earth. Because of this, the ground reflected wave tends to cancel the direct wave and hence a horizontally polarised aerial mounted near ground level has very poor low angle radiation. On the other hand, a vertically polarised wave does not change phase on reflection and it reinforces the direct wave. At low radiation angles, a loop aerial is vertically polarised and hence it can be mounted close to the ground and still give good low angle radiation. A good low conductivity ground might even improve the low angle signal.

So here is an added bonus. Not only is the transmitting loop physically small but it does not need to be mounted on a high mast or tower. In fact it could almost be mounted in any reasonable position and give good performance radiating both high and low angle radiation with a mixture of both forms of polarisation.

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